The short story of jet quenching and HIJING++

Balaton Worskhop 2019

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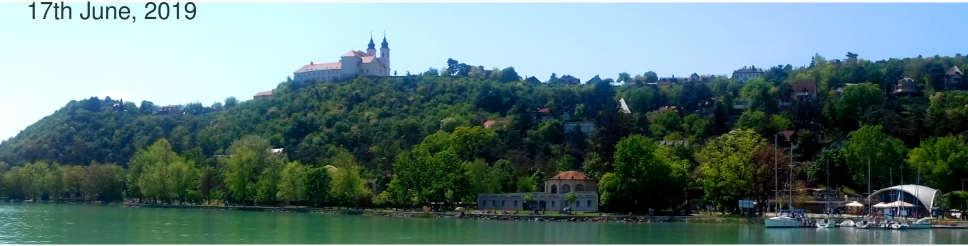

Collaboration

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Contents

HIJING++

- event generator for heavy ion collisions
- uses LHAPDF for PDFs
- uses PYTHIA (8.x) for nucleon-nucleon hard collisions (pQCD), and hadronization (Lund)
- does not use PYTHIA for
  - soft collisions
  - string arrangement
  - excited string radiaton
  - shadowing
  - Cronin effect
  - jet quenching

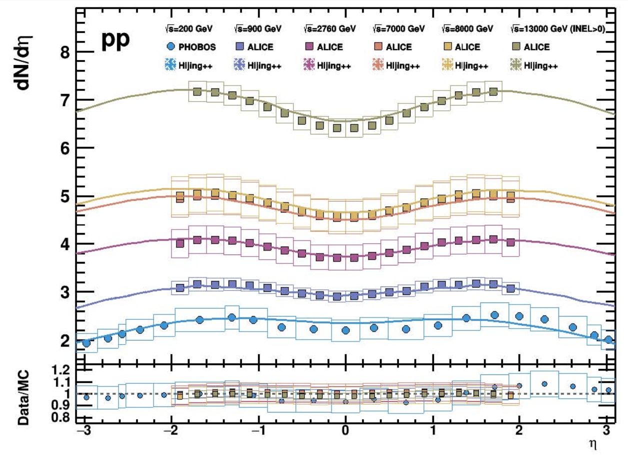

Figure 1: Pseudorapidity distribution from RHIC to LHC energies in *pp* colisions.

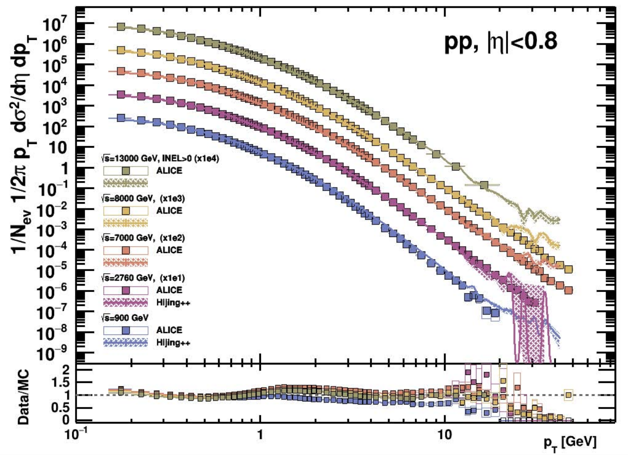

Figure 2: Invariant yield of charged hadrons at mid-rapidity at various CM energies in *pp* colisions.

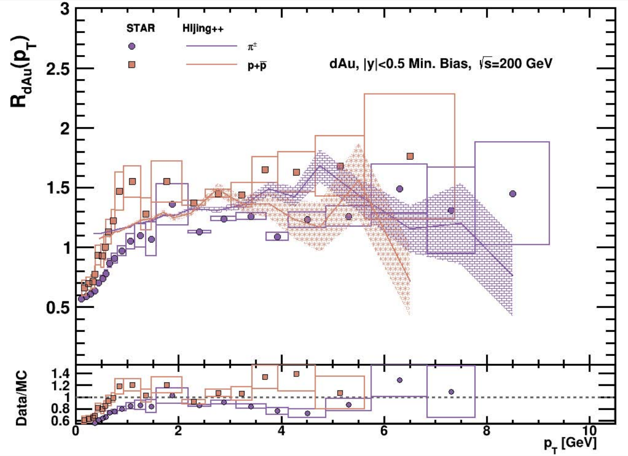

Figure 3: Nuclear modification factor in *dAu* 200 GeV collisions.

JET QUENCHING MODELS

Scale separation:

- *hard* particles produce vacuum shower (FSR)
- *semi-hard* particles interact with medium producing radiation
- jets modify the *soft* medium (heating, flow)

Usually analytically, we have a temperature and density dependence of the parameters, and a space-temporal description of the medium is required

Analytical models

- concentrating mainly on the jet (energy loss), parameterizing medium
- gives a clear qualitative picture
- sometimes no direct comparison to experiments is possible (multi-particle observables)

Monte-Carlo models

- full jet shower evolution is considered
- relies on analytical results with great simplifications

Jet quenching models

Time scale problem:

- the parton shower may take place in-medium, if there is enough time passing the medium to interact,
- or, like an "afterburner", a simple vacuum FSR takes place
- or, something in between ... (modification of splitting functions: Q-PYTHIA, MATTER, JEWEL; or modification of the already developed vacuum shower: MARTINI, PyQUEN, CoLBT, Hybrid, ...)

Processes for jet-quenching:

- is it simple sequence of parton-parton elastic collision (ZPC),
- or, radiation dominated,
- or, something in between ... (JEWEL, MARTINI, Co-LBT)

What's inside HIJING++

- It is an event generator, energy-momentum conservation should be fulfilled for all particles;
- single gluon emission will not do the job, hadronization may simply put is back to the jet ...;
- different steps are separated (FSR is separated from medium effects);
- there is no longitudinal separation, only transversal;
- there is no local parton density (but may be approximated);
- there is no local temperature (may be approximated???)
- tuned for speed

Which model to choose

Ask the wizard!

One day, when Miklos had nothing to do ...

Which model to choose

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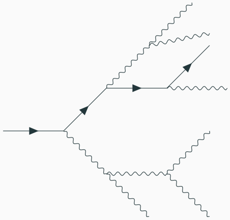
So let me try to reduce it to couple of minutes giving up on the clarity of the argument ...

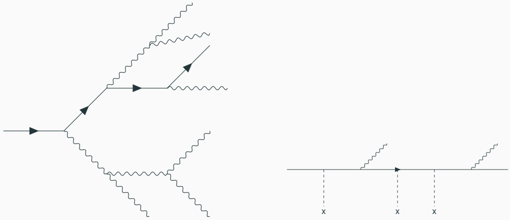
IMPLEMENTATION IN HIJING++: DGLV-CUJET

1. final state radiation: Sudakov factors from Poisson process of splittings (PYTHIA)



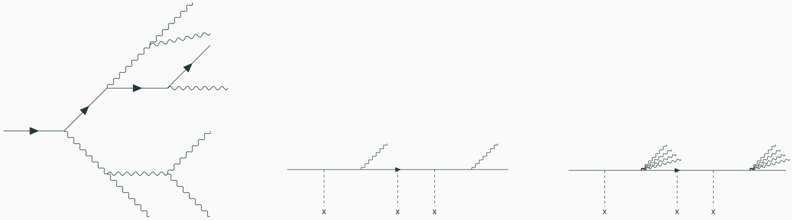
IMPLEMENTATION IN HIJING++: DGLV-CUJET

1. final state radiation: Sudakov factors from Poisson process of splittings (PYTHIA)
2. medium effects follow

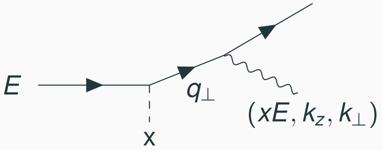


IMPLEMENTATION IN HIJING++: DGLV-CUJET

1. final state radiation: Sudakov factors from Poisson process of splittings (PYTHIA)
2. medium effects follow
3. FSR of gluons is done with ARIADNE



DGLV-CUJET FORMALISM



$$\frac{\mathrm{d}N_g}{\mathrm{d}x\mathrm{d}^2k_\perp\mathrm{d}^2q_\perp} = \underbrace{\frac{\alpha^2(gT)}{(q_\perp^2+\mu^2)^2}}_{\text{Rutherford}} \underbrace{\frac{(\vec{k_\perp}-\vec{q_\perp})\vec{k_\perp}}{((\vec{k_\perp}-\vec{q_\perp})^2+\mu^2)^2}}_{\text{antenna}} \left[1-\cos\left(\frac{(\vec{k_\perp}-\vec{q_\perp})^2+\chi^2}{2xE}\right)\right]$$

- μ is the Debye mass (electric, magnetic, lattice, ...),
- χ is related to the plasmon mass,
- formation time $t_f \approx \frac{k_\perp^2}{xE}$, shorter times: cancellation,
- BDMS limit: $q_\perp \to 0$.

DGLV-CUJET FORMALISM

The antenna term has an angle dependence

$$\frac{1 - 2z\cos\varphi}{(1 - 2z\cos\varphi + z^2 + \mu^2)^2}\,, \tag{1}$$

with $z = q_\perp / k_\perp$. This form has the following properties

- for $q_\perp \ll k_\perp$ it is always positive and may be interpreted as probability distribution;
- it has the maximum value at $\varphi = \pi$, preferring an anti-parallel positioning of $\vec{k_\perp}$ and $\vec{q_\perp}$;
- for $q_\perp \gtrsim k_\perp$ it may become negative, and cannot be interpreted as a probability distribution. Since this terms comes from the interference of the vacuum radiation and medium induced radiation, this is a legal behavior, meaning, that the interference tries to cancel radiated gluons coming with $k_\perp$ parallel to the jet transverse momentum, $q_\perp$, and rearranges them to anti-parallel configuration.

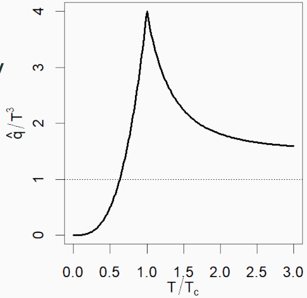
The secret recipe

- follow the path of the jet and determine string systems on the way;
- choose a parton from the string system, calculate the time τ of the closest approach;
- time order the collisions, then for each collision:
- cast transverse momentum $q_\perp$ of jet acquring from Rutherford scattering in random transverse direction;
- calculate energy loss, xE as $\frac{dE}{dL} = Q_{sat}^2 = \hat{q}L = \frac{xE}{L}$;
- cast transverse momentum $k_\perp < q_\perp$, and its angle φ of the emitted gluon from the “antenna” contribution;
- insert the emitted gluon to the string system;
- rearrange the excited string system (ARIADNE: “back effect on the medium”)

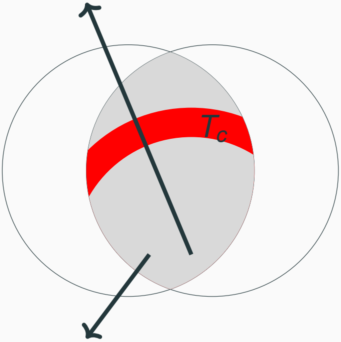
THE $\hat{q}$ PARAMETER

Jet quenching parameter $\hat{q} = \int \mathrm{d}^2 q \frac{\mathrm{d}\sigma}{\mathrm{d}q^2}\, q^2 \varrho(x)$,

- quantifies the transverse momentum squared exchanged between propagating jets and the nuclear medium;
- describes medium-induced radiative energy loss
- depends on the medium parameters
- $\frac{T^3}{\hat{q}} \begin{cases} \approx \eta/s & \text{weakly-coupled} \\ \ll \eta/s & \text{strongly-coupled} \end{cases}$



Overlap



- take into account the transverse expansion of the system:

$$T(\tau) = \frac{T_0}{\tau_0 + \tau},$$

where τ is the time needed for the jet to reach the given (transverse) region.

- non-trivial shape of strong interaction: extra contribution to flow parameters.

- knowledge of “local’ temperature” is required

SUMMARY

Summary

No summary